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A PROPOSED METHOD OF MEASURING ENGINE CHARGE

AIR FLOW IN FLIGHT

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CONFIDENTIAL BULLETIN

A PROPOSED METHOD OF MEASURING ENGINE CHARGE

AIR FLOW IN FLIGHT

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SUMMARY

A method is outlined for determining in flight the weight rate of air flow to the engine equipped with a Bendix-Stromberg injection-type carburetor. The method has the advantages that no additional equipment need be inserted in the charge-air system and only a few simple measurements are necessary. The analysis of an air-box calibration of the carburetor to be used in interpreting the flight measurements is shown by an example.

INTRODUCTION

Much difficulty has been experienced in measuring the weight rate of air flow to the engine in flight in order to determine fuel-air ratio or to investigate other phases of engine operation. When it is possible to insert an orifice plate or a Venturi in the induction system, additional losses are introduced in the system. Pitot-static traverses with a reasonable number of tubes do not usually define the velocity distribution with sufficient accuracy and, in some cases, are largely affected by turbulence. It has been found that, on airplanes equipped with the Bendix-Stromberg injection-type carburetor, charge air flow can be determined accurately within certain limits with a few relatively simple measurements. The method of interpreting these measurements is outlined herein.

METHOD

The air-measuring unit of the Bendix-Stromberg injection-type carburetor consists of a double Venturi

system as shown in figure 1. The pressure difference developed by this system is reduced by a density-compensating system to a value called the compensated metering pressure. The compensated metering pressure, acting through an arrangement of a diaphragm and a poppet valve, controls the pressure drop across the fuel jets. The method of determining air flow that is outlined here, however, is independent of the action of the density-compensating system and the fuel-metering system.

In a compressible fluid, such as air, the relationship between weight rate of flow and the pressure difference developed by a Venturi system may be expressed as

$$W^2 = 2g^2 A_2^2 \rho_1 H_1 f\left(\frac{P_2}{H_1}\right) \quad (1)$$

where

W weight rate of flow of air, pounds per second

g acceleration of gravity, feet per second per second

A₂ effective area of boost Venturi throat, square feet

ρ₁ density at entrance total pressure and temperature, slugs per cubic foot

H₁ absolute entrance total pressure, pounds per square foot

P₂ absolute static pressure at boost Venturi throat, pounds per square foot

For a single Venturi the function of the pressure ratio $f\left(\frac{P_2}{H_1}\right)$ can be expressed mathematically. For the system under consideration, however, the relative restrictions offered by the boost Venturi and the main Venturi are not constant, so that the proportion of the total air flow that passes through the boost Venturi is not constant and the pressure difference developed by the boost Venturi is a different function of the total air flow. It is therefore necessary to resort to a calibration of the Venturi system over the range of pressure ratio that will be encountered in flight.

Figure 2 shows a typical air-flow calibration of a Bendix-Stromberg injection-type carburetor plotted according to the generalized equation (1). Data plotted in figure 2 include air-box tests at ordinary room temperature at the inlet obtained from Bendix Aviation Corp. Stromberg Aviation Carburetor Dept. and Wright Field air-box tests both at room temperature and at approximately -40°F at the inlet (reference 1). Analyzed in this way, the characteristics of the Venturi system can be simply determined because only the range of pressure ratio need be investigated; that is, it is unnecessary to simulate temperatures or all possible combinations of density and air flow. Figure 3 illustrates better than figure 2 that the calibration is independent of temperature, when the data are analyzed in this manner. In figure 3(a) some of the data included in figure 2 are shown in the usual presentation as the pressure difference developed by the Venturi system for a range of entrance density at a constant air flow. For a given entrance density, the pressure difference varies with the temperature. In figure 3(b) the same data are plotted in the manner suggested by equation (1) and figure 2. The temperature effect disappears, and the relation between pressure ratio and the variable $W^2/2g^2\rho_1 H_1$ is shown to be independent of the temperature. The characteristics of the Venturi system can therefore be established by calibration tests at any desired temperature and can be specified by a single curve of the air-flow parameter $W^2/2g^2\rho_1 H_1$ throughout the desired range of pressure ratio.

ACCURACY

The experimental deviation of the measurement of air flow by the method outlined herein is within $\pm 1\frac{1}{2}$ percent for values of pressure ratio greater than 0.65. This deviation is shown in figure 4, where the percentage deviation of the factor $W^2/2g^2\rho_1 H_1$ from the faired curve of figure 2 is plotted against the pressure ratio. Except at high pressure ratios for which the low pressure differences could not be read from the calibration curves with sufficient accuracy, scatter of the data in the square of the air flow is of the order of ± 3 percent,

or in the air flow is of the order of $\pm 1\frac{1}{2}$ percent. This scatter is the same order of accuracy usually achieved in the determination of the air flow with the calibrating equipment used.

At pressure ratios less than 0.65, the scatter of the data increases until at a pressure ratio of approximately 0.40 the Venturi system becomes worthless as a measuring unit. Figure 2 shows that the minimum pressure ratio obtainable is approximately 0.40. Because theory indicates that pressure ratios less than 0.528 can be attained only in supersonic flow in an increasing area, the point of measurement in the boost Venturi is probably somewhat downstream of the effective throat of the Venturi. Theory further indicates that, for the relative areas necessary to satisfy the foregoing conditions, a pressure ratio of approximately 0.65 will be attained at the point of measurement when the speed of sound is just reached at the throat of the boost Venturi. The definite change in the character of carburetor calibration below a pressure ratio of 0.65 corresponds to the transition from subsonic to supersonic flow in the Venturi. It is evident from figure 4 that the flow in the boost Venturi cannot be definitely controlled under this condition and the accuracy of the unit as an air-flow measuring device is lessened.

According to reference 2, large changes in pressure distribution at the entrance to the carburetor may cause as much as 5-percent error in the measurement of air flow by the method outlined herein. In order to take into account any possible variation of this nature, the carburetor is usually calibrated with the duct in place to simulate flight conditions. Small changes in duct design will not appreciably affect the calibration, and carburetor duct installations that have efficient pressure recovery and therefore nearly uniform pressure distribution are almost equivalent to an ideal inlet as far as the carburetor calibration is concerned.

FLIGHT MEASUREMENTS

The necessary measurements to determine air flow in flight consist of absolute entrance pressure, total

entrance temperature, and boost Venturi suction. Taps are usually provided for measurements of these pressures. In addition to the usual carburetor-air temperature installation, an altimeter for absolute entrance pressure and an airspeed meter for the pressure difference are the only equipment needed.

FUEL-FLOW MEASUREMENTS

If an indication of fuel-air ratio is desired, fuel flow can be determined indirectly with the Bendix-Stromberg injection-type carburetor by measurement of the compensated air-metering pressure, inasmuch as both the fuel-metering pressure and the effective fuel-metering jet area are dependent upon this pressure difference. The measurement is inadequate at low fuel flows when the throttle is nearly closed because an additional restriction in the form of a variable-area idling jet is inserted in the fuel-measuring unit. Flight measurements, however, do not ordinarily extend into this region.

A flow-bench calibration of the carburetor is necessary for translating the measurements of air-metering pressure into fuel flow. If adequate fuel pressure indicates that no vapor is present in the fuel system, this measurement can be expected to give results as accurate as the ordinary flowmeter. For greater accuracy, a measurement of fuel temperature is desirable to take into account a change in fuel density from that used in calibration. The error in fuel flow due to change in temperature is of the order of 3 percent for 100° F.

CONCLUDING REMARKS

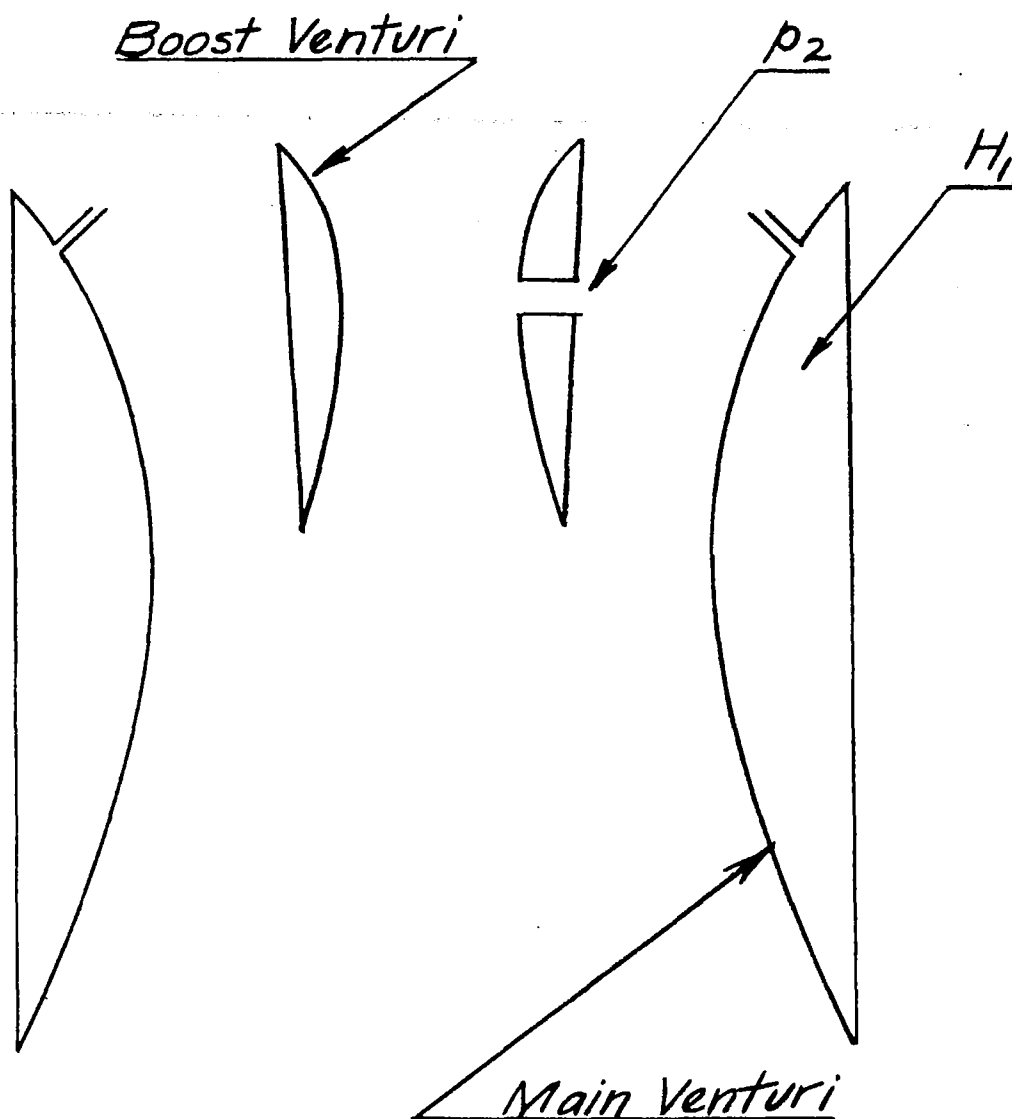
On the basis of the calibration test described herein, it is believed that an accurate determination of the weight rate of air flow to the engine may be obtained in flight on airplanes equipped with a Bendix-Stromberg injection-type carburetor, without the necessity for insertion of an additional measuring device in the charge-air ducts.

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1. Vanden-Heuvel, T. R.: PD18A1 Carburetor from the V-1650-3 Packard-Built Engine of the North American P-51B Airplane. Memo. Rep. No. ENG-57-430-652, Materiel Command Eng. Div., Army Air Forces, Sept. 3, 1943.
2. Kinghorn, George F.: Effect of Inlet-Air Velocity Distribution on the Metering Pressure of an Injection-Type Aircraft Carburetor. NACA ARR, May 1943.

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Figure 1.- Schematic drawing of air-measuring unit
of Bendix-Stromberg injection-type carburetor.

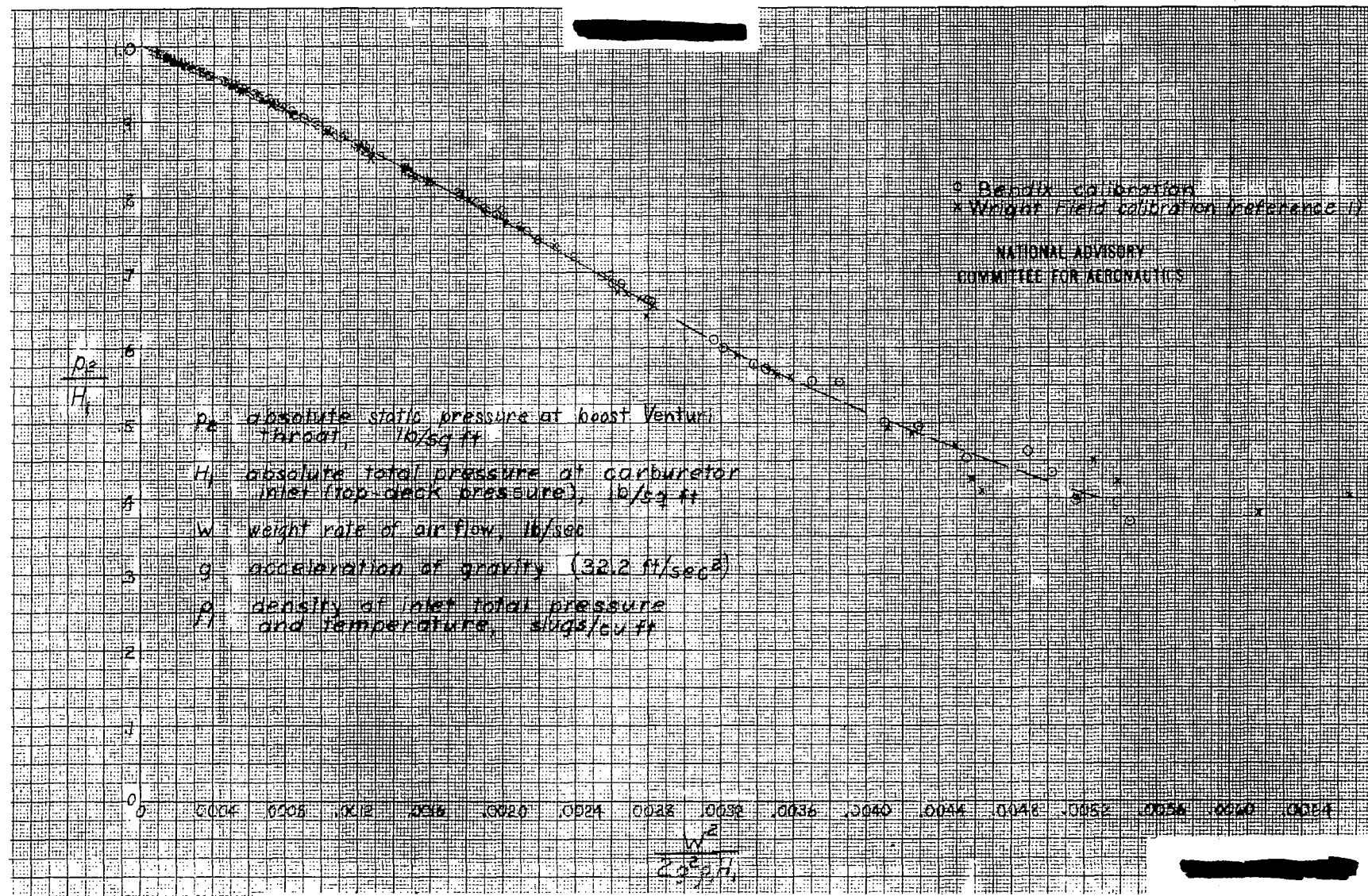


Figure 2.- Typical air-flow calibration of Bendix-Stromberg injection-type carburetor.

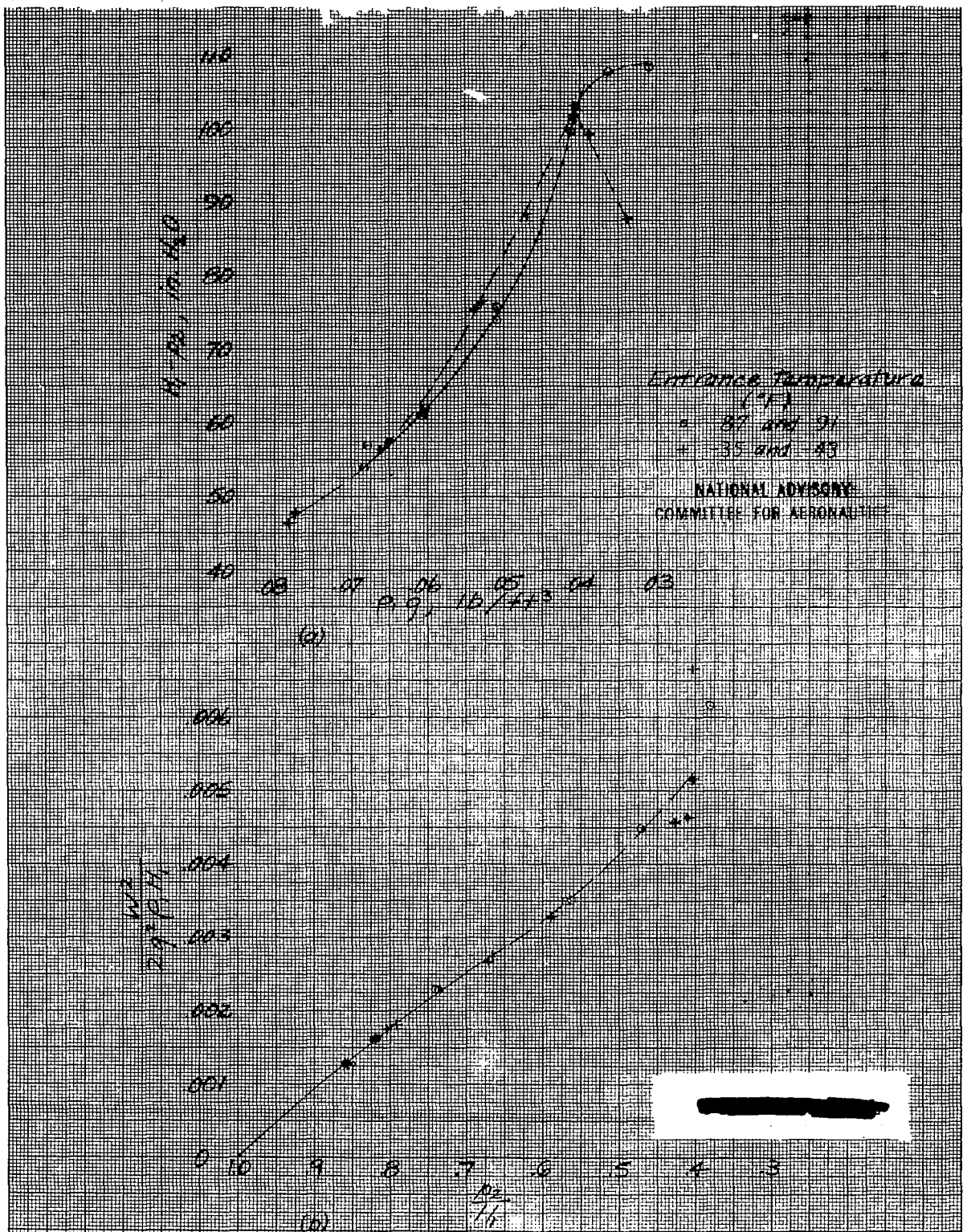


Figure 3.- Comparison of methods of presentation of air-flow calibrations for a typical Bendix-Stromberg injection-type carburetor. $W = 12,000$ pounds per hour.

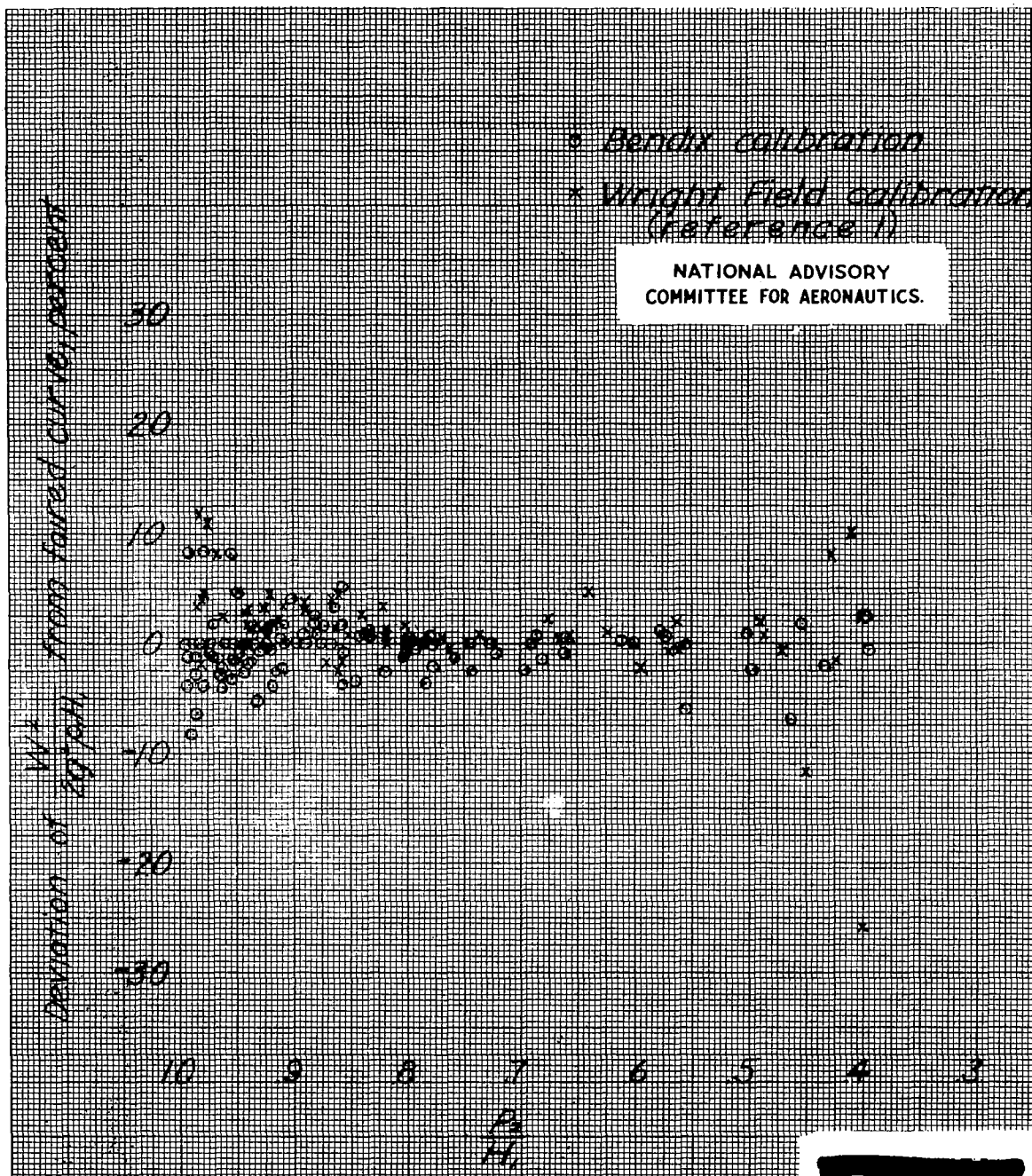


Figure 4.- Deviation of air-flow parameter from faired curve of figure 2.



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